Key Technologies of Tower CSP and Its Implementation on the Delingha 50MW Project

The SUPCON Delingha 50 MW Tower CSP project stands as one of China's first batch of concentrated solar power (CSP) demonstration projects. It is also listed among the national strategic emerging industries receiving key government support by the National Development and Reform Commission (NDRC). The project's designed annual electricity generation is 146 million kWh. Since commencing operation in 2019, it has continuously set new records. Specifically, the annual electricity generation reached 146.4 million kWh in 2022, achieving 100.26% of its designed annual capacity. In 2023, output climbed to 152.4 million kWh, reaching 104.38% of the design target. To date, this power station is the only tower molten salt CSP station globally to have achieved an average annual generation achievement rate exceeding 100% over three consecutive years. It serves as a benchmark for the design, construction, and operation of CSP plants worldwide.

Located in Delingha City, Haixi Prefecture, Qinghai Province, the project utilizes tower-type molten salt technology, equipped with a 7-hour molten salt thermal energy storage (TES) system. The solar field comprises 27,135 heliostats, each with a reflecting area of 20 square meters. Characterized by a vast number of control points, highly complex operating processes, and frequent disruptions due to adverse conditions such as cloudy weather, the project demands exceptionally high control requirements and poses significant optimization challenges. Through years of dedicated research and development, Cosin Solar developed and applied the following key technologies:

1. High-Precision Solar Concentrating Control Technology for Large-Scale Smart Heliostats: The project utilizes independently developed intelligent heliostat equipment featuring dynamic tracking and self-calibration. The heliostat field's

operation relies on three core models/algorithms:

1) Spatial Cluster Motion Model: Enables autonomous real-time tracking based on the dynamic position of the sun and the target receiver.
2) Machine Vision-Based Heliostat Deviation Detection and Nonlinear Least Squares Parameter Fitting/Calibration Algorithm: Solves the high-precision control challenge by enabling online automatic calibration of 800,000 parameters across the heliostat field. It achieves a tracking accuracy of 1.2 mrad (66% higher than the industry standard of 3.5 mrad).
3) High-Efficiency Coordinated Control System: Enables large-scale (100,000+ units), high-precision light concentrating across a heliostat field with a total concentrating area of 3.3 million square meters.

Third-Party Validation: German accessing agency CSP Services, in collaboration with the German Aerospace Center (DLR), evaluated multiple heliostat sets installed at various positions within the heliostat field of the project. Test results confirmed the heliostats' exceptional advantages, including minimal surface error and high tracking accuracy. The tracking performance, in particular, received an "Excellent" rating.

2. Safe and Efficient Heat Collection Technology with Dynamic Energy Dispatch for High-Temperature Receivers:

The heat collection system employs a high-focus-ratio solar flux distribution model. This model enables the global design and optimization of solar energy harvesting across the heliostat field under multiple constraints, coordinates large-scale heliostat field energy dispatch into the high-temperature receiver using grid-based dynamic control methodology, contactless infrared-based, full-dimensional surface temperature field measurement, and dynamic aiming point control strategy to ensure uniform energy distribution across the receiver surface and precisely limits temperature gradients and fluctuations during transients. It also integrates multi-modal data analysis, using short-term regional cloud forecasting algorithms to enable adaptive, intelligent operation under complex meteorological conditions, such as cloudy skies, which significantly reduces thermal shock on the receiver, ensuring its safe operation. Furthermore, it substantially increases solar energy utilization by the heliostat field during cloudy days (as shown in Table 1).

Table 1 Comparison of performance between manual control and intelligent control

	Date	DNI (kWh/㎡)	Curtailed Ratio (%)	Actual Energy (MWh)	Theoretical Energy (MWh)	Achievement rate (%)
Manual	2023/3/20	5.00	44.84	621.9	815.9	76.22
Intelligent control	2025/3/20	4.97	23.39	962.4	901.0	106.81↑

3. Safe and Reliable High-Capacity Molten Salt Energy Storage and Peak Shaving Technology: Utilizing a temperature-controlled preheating buffer molten salt tank, it supports maximum temperatures up to 560°C and a maximum scale of 4900MWhe. The cold/hot molten salt dual-tank thermal storage system decouples the heat absorption and power generation processes, resolving the contradiction between unstable solar radiation and stable grid electricity demand. Employing a dual-row heat exchange system and hairpin heat exchangers, it achieves wide-range rapid load variation and deep flexible peak shaving, surpassing that of thermal power plants, enabling a load adjustment range of 15%-100% with a ramping rate of 5% per minute.

The Delingha 50MW plant achieved an actual annual power generation attainment rate of 94.35% during its first full year of operation after being handed over to production. Through the successful application of the aforementioned core equipment, control systems, and software, the plant achieved its highest full-year power generation achievement rate of 108.3%, and it has consecutively met its power generation targets for three consecutive years. Following technical evaluation and verification by the internationally authoritative independent engineering consultancy Fichtner (Germany), the plant's design has reached the state-of-the-art level globally for similar technologies, with key equipment in good operating condition and featuring several design highlights such as the heliostat and its control system design, minimized molten salt pump quantity design, and steam cycle system design. The overall conclusion of the evaluation report states that this CSP plant possesses a level comparable to that of international technology providers. The series of novel design methods adopted have effectively enhanced the plant's performance and operational and maintenance level.